**Plastic Pipes and Residential Piping Systems**

Product Selection and Description

The Plastic Piping Education Foundation (PPEF) was founded in 1987 by the Plastic Pipe and Fittings Association (PPFA) to develop and advance the knowledge of plastic piping systems. PPEF commissioned Franklin Associates, a Division of ERG, to assess the environmental profiles of commonly used materials for three categories of plastic pipes used in buildings: service line pipe (i.e., underground pipe running from the water main to the house), hot and cold water distribution (HCWD) pipe, and drain/waste/vent (DWV) pipe. The plastic pipe models and this documentation in BEES are based directly on this PPEF study.[1]

BEES evaluates pipe systems for the three use categories on a linear basis, using a functional unit of 305 m (1000 ft) of each pipe over a period of 50 years. All life cycle stages – including pipe fittings and installation – are normalized to 305 m (1000 ft) of pipe, and energy and water losses over the use phase are excluded. Table 1 describes the product alternatives for each use category.

***Table 1: Plastic Pipe Systems in BEES***

| Use Category | | Pipe Product Alternatives |
|---|---|---|
| **Service line**<br>2.5 cm (1 in) diameter | 1 | PVC pipe |
| | 2 | Polyethylene (PE) pipe |
| **HCWD**<br>1.9 cm (3/4 in) diameter | 1 | Chlorinated Polyvinyl Chloride (CPVC) pipe with CPVC fittings, installed with adhesive |
| | 2 | Cross-Linked Polyethylene (PEX) pipe installed with a mixture of brass and polysulfone fittings |
| **DWV**<br>10.2 cm (4 in) diameter | 1 | Solid Polyvinyl Chloride (PVC) pipe with PVC fittings, installed with solvent cement (adhesive) |
| | 2 | Cell core PVC pipe with PVC fittings, installed with adhesive |
| | 3 | Solid Acrylonitrile-Butadiene-Styrene (ABS) pipe with ABS fittings, installed with adhesive |
| | 4 | Cell core ABS pipe with ABS fittings, installed with adhesive |

BEES also includes models for CPVC and PEX HCWD pipes in two whole-house layouts: a one-story 127 $m^2$ (1367 $ft^2$) square foot residential building ("smaller house") and a two-story 409 $m^2$ (4402 $ft^2$) residential building ("larger house"). For these models, the functional unit is the quantity of pipe, fittings, and installation materials required for each layout. Energy and water losses during the use phase is included, based on residential simulation results from the Davis Energy hot water simulation tool, HWSim.[2]

## Flow Diagram

Figures 1 and 2 illustrate the major elements of the production of the products evaluated on a linear basis and a house layout basis, respectively, as they are modeled for BEES.

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[1] Franklin Associates, A Division of ERG, *Peer Reviewed Life Cycle Inventory for the Production and Use of Installed Residential Piping Systems for Three House Layouts* (Glen Ellyn, Illinois: Plastic Piping Education Foundation, February 2011), retrieved from http://www.ppfahome.org/pdf/Peer_Reviewed_Pipe_Use_Phase_Report_combined_Final.pdf.

[2] Davis Energy Group, Inc. HWSim. Accessed at: http://www.davisenergy.com/projects/hwsim.php.

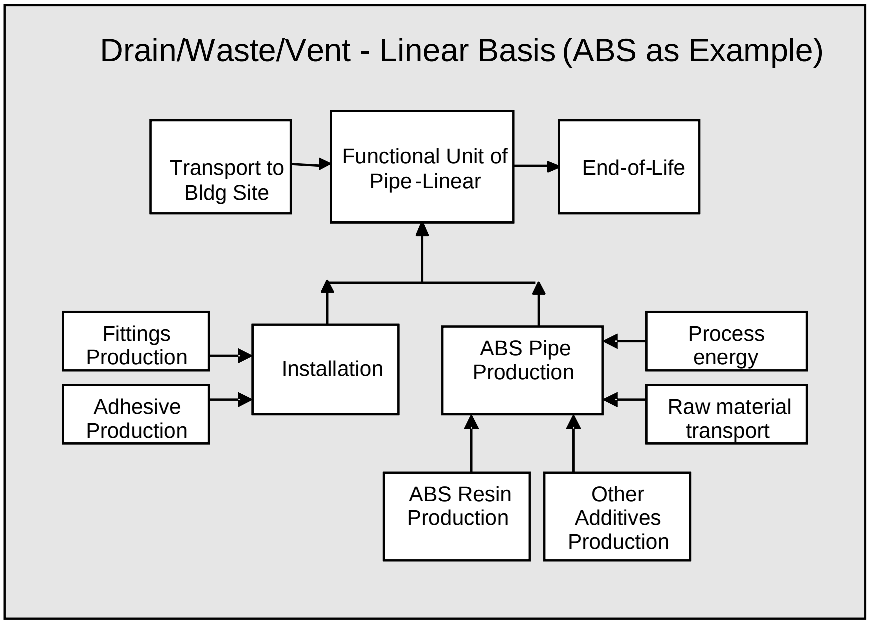


*Figure 1: Plastic Pipe on Linear Basis System Boundaries*

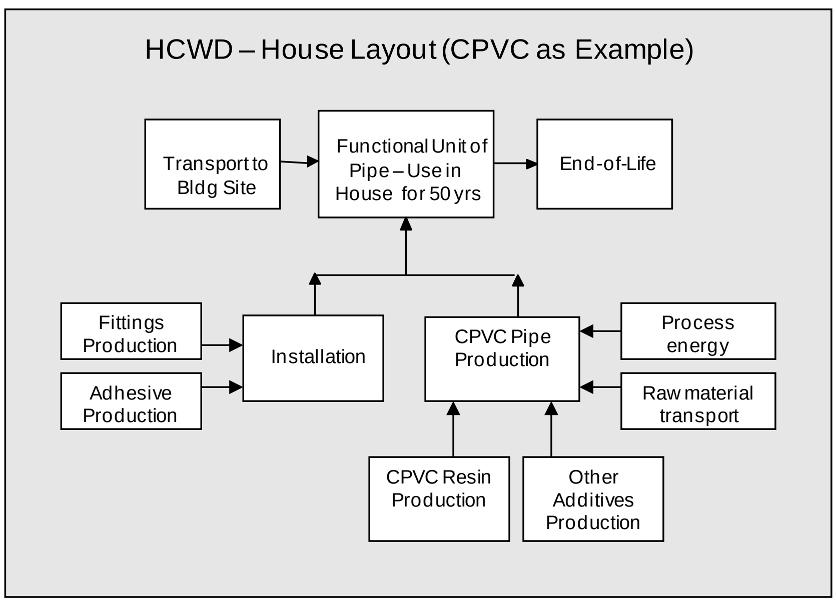


*Figure 2: Plastic Pipe on House Layout Basis System Boundaries*

**System Details**

The table below presents the quantities of pipe, fitting, and adhesive material per 305 m (1000 ft).

***Table 2: Pipes on Linear Basis – Functional Unit Details****

| Use | Material | Density kg/m (lb/ft) | kg (lb) material /functional unit | Fitting type & kg (lb)/functional unit | Adhesive kg (lb) /functional unit |
|---|---|---|---|---|---|
| Service line | PVC | 0.49 (0.32) | 144 (317) | PVC: 2.7 (6.0) | 0.54 (1.2) |
| | Polyethylene | 0.23 (0.16) | 71 (156) | None** | none |
| HCWD | CPVC | 0.2 (0.14) | 62 (137) | CPVC: 5.9 (13 ) | 1.5 (3.3) |
| | PEX | 0.16 (0.11) | 51 (112) | PS & brass:3.5(7.6) | none |
| DWV | PVC | 3.02 (2.02) | 917 (2021) | PVC: 220 (484) | 13.6 (30) |
| | PVC Cell Core | 1.9 (1.27) | 575 (1267) | PVC: 220 (484) | 13.6 (30) |
| | ABS | 2.23 (1.50) | 682 (1504) | ABS: 176 (389) | 13.6 (30) |
| | ABS Cell Core | 1.51 (1.01) | 457 (1007) | ABS: 176 (389) | 13.6 (30) |

* Calculated values may differ slightly due to rounding of the densities. Pipe weights come from pipe producer LCI data collected for the Franklin study.

** PE service pipe does not require adhesive for installation and is instead joined via either a heat or mechanical process. Energy requirements for using heat to connect the lengths of PE service pipe were assumed to be small in comparison to pipe production impacts, and no associated data were available, so the energy for these connections was excluded from the study.

Tables 3 and 4 present the length of pipe and associated quantities of pipe materials, fitting materials, and adhesive in the smaller and larger house layouts. Pipe layouts for each home were provided by PPEF for its study. The layouts for the hot water tubing are traditional trunk and branch designs from the Davis Energy models. The layouts for the cold water tubing mirrored the hot water tubing, with additional tubing and fittings for water closets and hose bibbs. Appendix A of the PPEF study presents the house layout diagrams and pipe details.

Weights of individual fittings and pipe types in the layouts were modeled based on data provided by pipe and fittings manufacturers and from on-line catalogs. Total weight of fittings and pipe per layout were obtained by multiplying the weights of fittings and pipes by the number of fittings and the length of pipe in the layout. Quantity of adhesive used for installation was based on volume required per joint, calculated based on the E-Z Weld, Inc. Calculator Tool provided by PPFA.[3]

[3] For more information, go to http://www.e-zweld.com/.

*Table 3: HCWD Pipes as Used in the Smaller House – Functional Unit Details*

| | CPVC | PEX |
|---|---|---|
| Length of pipe – m (ft) | 80.8 (265) | 80.8 (265) |
| Total weight of pipe – kg (lb) | 12.4 (27.3) | 9.3 (20.5) |
| Total weight of fittings – kg (lb) | 1.3 (2.9) | 1.0 (2.2) |
| Total weight of adhesive – kg (lb) | 0.54 (1.2) | -- |

*Table 4: HCWD Pipes as Used in the Larger House – Functional Unit Details*

| | CPVC | PEX |
|---|---|---|
| Length of pipe – m (ft) | 168.6 (553) | 168.6 (553) |
| Total weight of pipe – kg (lb) | 30.1 (66.3) | 22.5 (49.7) |
| Total weight of fittings – kg (lb) | 2.8 (6.2) | 2.4 (5.4) |
| Total weight of adhesive – kg (lb) | 1.1 (2.4) | -- |

The PPEF study notes that while the house layouts represent a range of house sizes, the pipe layouts within each house are specific pipe layouts, and should not be considered the only design for pipe installations for all houses of similar square footage.

**Raw Materials**

*Raw materials for plastic pipes.* The following tables present the constituents by mass fraction for the pipe products.

*Table 5: Water Supply Pipe Constituents*

| Pipe Material | *Constituent* | *Mass Fraction* |
|---|---|---|
| PVC | PVC resin | 92.5 % |
| | Calcium carbonate | 4.7 % |
| | Other additives | 2.8 % |
| | **Total** | **100 %** |
| Polyethylene | HDPE resin | 94.7 % |
| | LLDPE resin | 5.3 % |
| | **Total** | **100 %** |

*Table 6: HCWD Pipe Constituents*

| Pipe Material | *Constituent* | *Mass Fraction* |
|---|---|---|
| CPVC | PVC resin | 66 % |
| | Chlorine | 18 % |
| | Calcium carbonate | 4.2 % |
| | Impact modifier | 6.3 % |
| | Other additives | 5.5 % |
| | **Total** | **100 %** |
| PEX | PEX-b compound | 25 % |
| | PE resin | 74.3 % |
| | Other additives | 0.7 % |
| | **Total** | **100 %** |

*Table 7: DWV Pipe Constituents*

| Pipe Material | *Constituent* | *Mass Fraction* |
|---|---|---|
| PVC | PVC resin | 92.4 % |
| | Calcium carbonate | 4.7 % |

| | | |
|---|---|---|
| | Other additives | 2.9 % |
| | **Total** | **100 %** |
| PVC Cell Core | PVC resin | 87.3 % |
| | Calcium carbonate | 7.9 % |
| | Other additives | 4.8 % |
| | **Total** | **100 %** |
| ABS | ABS resin | 100 % |
| | Other additives | <0.01 % |
| | **Total** | **100 %** |
| ABS Cell Core | ABS resin | 97.7 % |
| | Other additives | 2.3 % |
| | **Total** | **100 %** |

Main resins. Data for PVC, ABS, HDPE, and LLDPE come from the U.S. LCI Database. CPVC production data come from the PPEF study, which used life cycle data published in one company's environmental brochure for a CPVC resin which is derived from PVC resin. Process inputs, energy, and other process data for PEX production are based on primary data from PEX producers collected for the PPEF study.

Other raw materials. Calcium carbonate and chlorine come from the U.S. LCI Database. The acrylic resin impact modifier is modeled as polymethylmethacrylate (PMMA) which comes from PlasticsEurope.[4] Color concentrate, used in the HDPE and LLDPE resins in the polyethylene water supply pipe, totaled less than 1 % of the product so was modeled as the resin itself (as proxy data).

Other additives. The other additives categories in the tables above include polyethylene and paraffin waxes, titanium dioxide, calcium stearate, and peroxide. These materials were modeled based on the U.S. LCI database, where available, and EcoInvent and other elements of the SimaPro database. Organotin heat stabilizer, blowing agent for cell core pipes, and antioxidants make up the remainder of the additives; these have been excluded since they total less than 1 % by weight of pipe system and since composition and production data were not available.

*Raw materials for pipe fittings and adhesive.* The fitting materials used for the CPVC, PVC, and ABS pipes are comprised primarily of – and modeled as – their respective plastic pipes. PEX pipe is installed with brass fittings or a mixture of brass and polysulfone (PS) resin. For the BEES model, the mixture of brass and PS resin was used, with PS representing 60 % to 66 % by weight of the fittings. PS resin production was modeled using proprietary data used for the PPEF study.

The composition for the adhesive used for BEES was provided by a PPFA expert for the PPEF study: 30 % tetrahydrofuran, 40 % methyl ethyl ketone, 15 % cyclohexanone, and 15 % resin. The resin data come from the U.S. LCI Database and the remaining components come from EcoInvent.

**Manufacturing**

Plastic pipes are produced by extrusion. PVC, CPVC, ABS, and PE pipes undergo a solid extrusion pipe process, in which a tube is formed by using mechanical and thermal energy to melt a thermoplastic resin and force it through a die. The PVC and ABS cellular core pipes undergo a similar extrusion process; according to the PPEF study, the cellular core construction involves the simultaneous extrusion of three layers into the pipe wall: a solid outer layer, a solid inner layer, and a lower density foam intermediate layer that holds the outer and inner layers in position with each other. PEX pipes are fabricated using special extruders engineered to fabricate pipes from PEX produced by the Engel or peroxide method (PEX-a) and the Silane method (PEX-b).[5]

[4] PlasticsEurope Ecoprofile data may be obtained at http://lca.plasticseurope.org/

[5] None of the pipe producers contributing data to the PPEF project reported using a third PEX production method, the electronic

For pipe fabrication, data come from plants in North America (all are in the U.S. except for two in Canada). Fittings fabrication data come from plants in the U.S., Canada, and Asia. All data are based on weighted averages of the facilities that provided data.

*Energy Requirements.* For this study, resin heating and pipe extrusion energy inputs, air emissions, water effluents (where applicable), and process waste were provided by pipe producers and have been included in the BEES modeling. The electrical energy is provided in the table below; data for all energy pre-combustion and use comes from the U.S. LCI database.

***Table 8: Pipe Manufacturing Energy***

| Use | Material | MJ/kg (kWh/1000 lbs pipe) | MJ/m (kWh/1000 ft pipe) |
|---|---|---|---|
| Service line | PVC | 1.1 (138) | 0.52 (44) |
| | Polyethylene | 1.79 (226) | 0.41 (35) |
| HCWD | CPVC | 1.7 (214*) | 0.34 (29) |
| | PEX | 4.31 (543**) | 0.72 (61) |
| DWV | PVC | 0.8 (101) | 2.42 (205) |
| | PVC Cell Core | 0.96 (121) | 1.82 (154) |
| | ABS | 1.56 (197) | 3.51 (297) |
| | ABS Cell Core | 0.79 (100) | 1.19 (101) |

* Compounding the CPVC plus pipe production
** Compounding the PEX plus pipe production

*Transportation.* Transportation distances for shipment of the raw materials from suppliers to manufacturing plants were provided by each manufacturer. Weighted averages of the shipping distances to manufacturers were calculated. For 454 kg (1000 lb) of each pipe type, distances ranged from 0.3 t-km to 96 t-km (0.2 ton-mi to 66 ton-mi) by truck, 416 t-km to 1241 t-km (285 ton-mi to 850 ton-mi) by rail, and 200 t-km to 2855 t-km (137 ton-mi to 1956 ton-mi) by ocean freighter. All transportation models were based on the U.S. LCI database.

### Transportation

On average, the transportation distance from pipe manufacturers to the installation site was calculated to be 928 km (577 mi). The pipes are shipped by diesel truck, which is modeled based on data from the U.S. LCI database.

### Installation

Installation includes application of the fittings and adhesive (materials described above). No excavation or other site preparation energy was included, and no energy use was modeled for cutting pipe to length or use of heat for bonding joints. Installation scrap for plastic pipe was estimated based on information provided by PPFA for the PPEF study, and this is accounted for in the production stage of the models.

### Use Phase

The use phase was modeled for the CPVC and PEX HCWD pipe systems in the two house layouts using output from the Davis Energy Group's HWSim Model. For the purpose of this study, use accounts for the water and

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beam or radiation method, so this was not included.

energy *losses* associated with hot water distribution: 1) water that is wasted while running the water at the sources of use until the hot water reaches the desired temperature and 2) the heat wasted as hot water cools down in the distribution system between draws.

The use phase modeling assumed four occupants in the house with a daily indoor delivered water use of 0.15 $m^3$ (39.7 gal),[6] from showers, baths, the clothes washer, the dishwasher, and faucets in the kitchen and bathrooms. This water quantity does not include leaks or water uses without an associated draw/heating requirement (e.g. toilets). Two basic use patterns have been modeled for each house layout: clustered and cold-start.[7] The cold start use pattern assumes water draw throughout the day, so water reaches the ambient temperature surrounding the pipe before each use (hot water in the pipe cools between uses). The clustered use pattern assumes the water draws are clustered in the early morning and late afternoon during the weekdays, so that there is minimal cooling of hot water between draws in the morning and evening. During the weekend while occupants spend more time at home, the cold start use pattern was applied. The PPEF study notes that these two use patterns were modeled to cover the widest range for a realistic situation, and actual residential water use patterns most likely vary between these extremes.

The models assume that an equivalent volume of water is delivered to the consumer for each pipe type, house layout, and use pattern. The heat loss and wasted water calculations are based on the thermal conductivity of the pipe materials and the temperature differential between 54 °C (130 °F) water in the pipes and surroundings at a constant temperature of 16 °C (60 °F). The water heater is a gas storage tank and the model assumes an energy factor of 0.62 (62 % of energy used in water heater reaches consumer), based on the U.S. Department of Energy's ENERGY STAR criteria for a gas storage water heater.[8] The following tables present the natural gas energy and water losses over the 50 year time horizon for both house layouts.

***Table 9: Energy and Water Losses over 50 Years – Smaller House***

| **Pipe Material, Use Pattern** | ***Natural gas 1000 MJ (1000 $ft^3$)*** | ***Water $m^3$(1000 gal)*** |
|---|---|---|
| CPVC Cold Start | 204.8 (189.0) | 440.9 (116.4) |
| CPVC Clustered | 187.3 (172.8) | 397.7 (105.0) |
| PEX Cold Start | 219.0 (202.1) | 481.1 (127.0) |
| PEX Clustered | 205.1 (189.3) | 460.6 (121.6) |

***Table 10: Energy and Water Losses over 50 Years – Larger House***

| **Pipe Material, Use Pattern** | ***Natural gas 1000 MJ (1000 $ft^3$)*** | ***Water $m^3$(1000 gal)*** |
|---|---|---|
| CPVC Cold Start | 555.7 (512.8) | 1301.0 (343.5) |
| CPVC Clustered | 382.7 (353.2) | 870.1 (229.7) |
| PEX Cold Start | 575.9 (531.5) | 1434.7 (378.8) |
| PEX Clustered | 410.9 (379.3) | 953.8 (251.8) |

The minimum useful life for the plastic pipes was estimated in the PPEF study to be greater than 50 years for all pipe types[9] so no replacement of pipe was necessary for the BEES study period. Please refer to Chapter 2 of the PPEF study for detailed information and data sources on service life and pipe erosion. Regarding maintenance, according to the PPEF study, installed pipe generally does not require repair during the life of the building in

[6] Quantity used in the Franklin study; data from American Water Works Association for specific use points.
[7] Use patterns follow the methodology laid out in Oak Ridge National Laboratory's report on Residential Hot Water Distribution Systems by Numeric Simulation (2004), found at http://www.ornl.gov/~webworks/cppr/y2001/rpt/122464.pdf.
[8] US EPA. Energy Star Criteria. Accessed at: http://www.energystar.gov/ia/partners/prod_development/new_specs/downloads/water_heaters/WaterHeater_ProgramRequirements.pdf, for period ending 8/31/2010.
[9] Accurate Inspection Services, Inc. Life Expectancies of Residential House Components.

which it is installed, although there are occasional exceptions, such as pipes that burst due to freezing. No failures of this type were modeled in the PPEF study or BEES.

### End-of-Life

At end of life, all plastic pipe types are assumed to be disposed of in a landfill an assumed average of 64 km (40 mi) from the use location. Transportation to the landfill by diesel truck has been accounted for; the truck model is based on the U.S. LCI Database.

### References

**Life Cycle Data**


Franklin Associates, A Division of ERG: *Peer Reviewed Life Cycle Inventory for the Production and Use of Installed Residential Piping Systems for Three House Layouts* (Glen Ellyn, Illinois: Plastic Piping Education Foundation, February 2011), retrieved from http://www.ppfahome.org/pdf/Peer_Reviewed_Pipe_Use_Phase_Report_combined_Final.pdf.

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**Industry Contacts**

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